Characterizing Quantum Tunneling Composite for Use in the Manual Wheelchair Virtual Seating Coach

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INTRODUCTION

There are about 3.6 million wheelchair users in the United States [1]. Wheelchair users are at risk of incurring pressure ulcers, which result from constant pressure on the skin by staying in one position for an extended amount of time [2]. The prevalence of pressure sores in the United States is about 13% and treatment can cost up to $70,000. Clinicians recommend periodic weight shifting (every 15-30 minutes) for pressure management and decreasing the chance of developing pressure ulcers, but it was found that only about 20.8% of manual wheelchair users (MWU) do so once an hour with the rest of the subpopulation having an even lower frequency [3]. Currently, there are various tools that provide regular reminders to perform pressure relief but fail to improve compliance or evaluate the effectiveness of the action [4].

The Manual Wheelchair Virtual Seating Coach (MW-VSC) is an extension of previous work on a Power Seat Function Virtual Seating Coach that implements intelligent reminders and evaluation of pressure relief actions [5]. It is a smartphone app that tracks the user's center of pressure and reminds users to complete a pressure relief. It maps pressure with a system of strain gages under the seat pan. While this system performed well at measuring the user's weight shifts, the materials and set up time for the implementation are cost prohibitive. A cheaper alternative to strain gages, such as quantum tunneling composites (QTCs) for 10 cents per pill, is desired.

QTCs are composite materials consisting of an insulating elastomeric binder and irregularly-shaped metal particles (100nm-500nm) dispersed throughout the binder without contact with other metal particles [6]. QTC resistance decreases with deformation, so they can act as pressure or force sensors. They utilize quantum tunneling. Uncompressed, they act as a perfect insulator with infinite resistance. When compressed, the metal particles are pushed closer together (with no contact), which increases the probability of an electron from one metal particle tunneling through the polymeric material to another metal particle, establishing conductance. QTCs demonstrate a relationship of logarithmic decay between resistance and amount of force applied; their resistance decreases sharply towards 0Ω to become a near-perfect conductor as deformation increases.

However, QTC are not well documented otherwise. Peratech suggests that the load that elicits maximum response from the QTC is 100N or about 22 pounds [7]. Hence, the objective of this study is to characterize QTC to evaluate their viability as pressure sensors for the MW-VSC.

METHOD

<u>Setup</u>

The parameters of data collection include voltage vs. weight and hysteresis. These were observed for individual QTCs and for two QTCs stacked one atop another. A QTC pill is 3.6mm x 3.6mm x 1mm. Tests were conducted at room temperature.

Two flat blocks (one plexiglass, one wood) each had 3 copper strips (50mm x 5mm x 75µm) taped to the block with space exposed for placing the QTCs on the inner ends to configure an

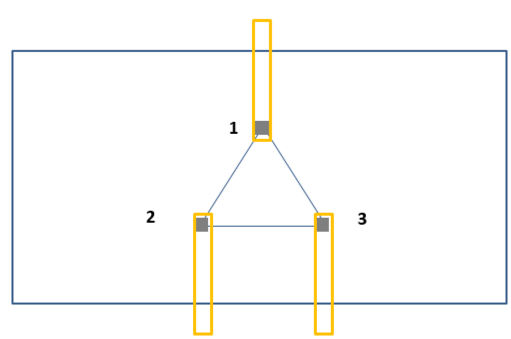

Figure 1. Configuration of the QTCs on each block with positions numbered

equilateral triangle of length 1 inch, as seen in Figure 1. These positions will be referred to as Single QTC # or Stacked QTC #, where #=1, 2, or 3 in correspondence with the labels in Figure 1. The load was placed in the center so that the weight was evenly distributed among the three QTCs. The QTCs were sandwiched between the two blocks and integrated into a voltage divider.

A program was written in C, the flow of which is illustrated by Figure 2. Voltage was measured by the Pmod AD2, a 4-channel, 12-bit analog to digital converter (ADC). The ADC transmitted data to the Raspberry Pi 3 over the I^2C bus. The timestamp of each measurement and the voltage over each QTC were written to a text file for data analysis. The system continuously collected data at a rate of 240Hz until Button 2 is pressed. Button 1 is used to record the time at which a weight was added. A DC voltage source of 5.48V from the raspberry Pi provided power to the QTC system prototype. If the QTC is uncompressed, then the voltage read in the ADC would be 0V or close to 0V. If the QTC is as deformed as possible, the ADC would read about 5.5V.

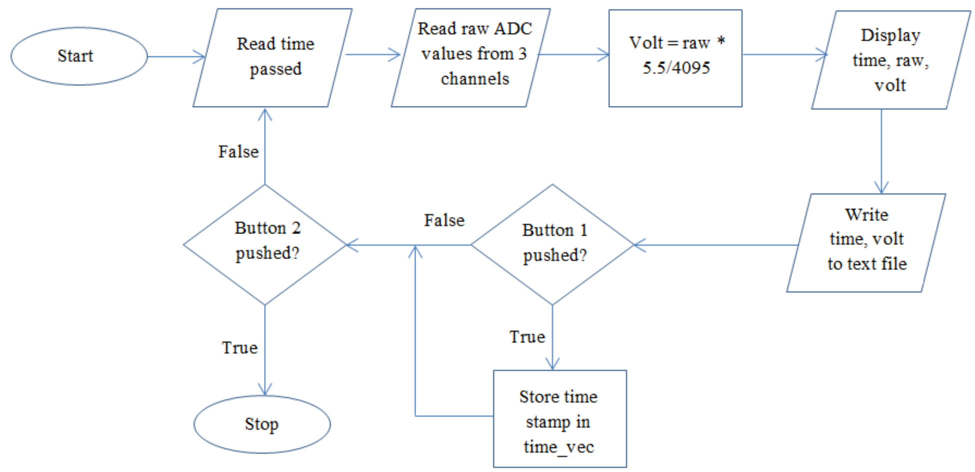

Figure 2. Block Diagram of Program

Data Collection

Five trials were conducted. Based on available weights, voltage was observed for the following forces in pounds 0, 2.2, 11, 21, 29.8, and 54.8. Weight was added about every 30 seconds; a button was pushed when a weight was added to obtain the timestamp of the addition. Then weight was removed (from 54.8 to 29.8 and so on) every 30 seconds for determination of hysteresis. One trial overall is 5.5 minutes. Data collection is stopped with the push of Button 2.

RESULTS

Plotting QTC voltage (in terms of volts) over time (in terms of milliseconds) on Excel yielded scatter plots that remain relatively steady for no weight and for max weight applied, but demonstrated a notable amount of scatter in between, as seen in Figure 3 for QTC Position 2. Each position for both single and stacked demonstrated a similar trend. For further analysis, the QTC voltage for each weight was averaged over the weight's respective time interval, yielding 6 points for each half trial. They were plotted against weight in terms of position and a best-fit exponential curve was applied to the plot in MATLAB, as seen in Figure 4. Error bars represent the standard deviation of each point. The standard deviation tended to be larger

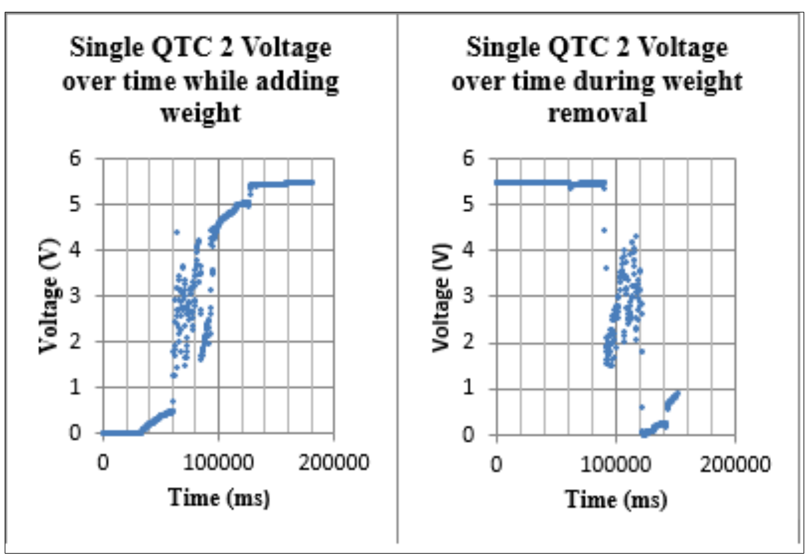

Figure 3. Raw data of voltage over time for QTC Position 2

during the adding weight phase, particularly during the first half. Standard deviations tended to be very close to zero- on a scale of hundredths- when there was maximum load applied to the QTCs.

The R^2 coefficient determined by MATLAB conveyed how well the curve fits the data. The equation of the best-fit curve and the R^2 coefficient for each QTC position are listed in the legend of each graph in Figure 6. Each curve demonstrated high correlation, with R^2 being 1 or close to 1, between voltage and weight in the form of ($V = a\, e^{-bx} + c$), or V equals a times e to the product of negative b and x, and that is summed with c. The quantity x is the weight of the load in terms of pounds.

The lowest R^2 coefficient was 0.9622 with QTC Stack 2 for weight removal. A one-way ANOVA ($\alpha = 0.05$) test on the averages over each QTC position, individual or stacked, revealed that there are no statically significant differences among them.

The data also demonstrated some hysteresis, shown in Table 1. Hysteresis for a QTC position was obtained by finding the difference between the area under the curve for when weight was added and for that of when weight was removed. When weight is being removed, there is a delay in the QTC uncompressing compared to compression from when weight was being added.

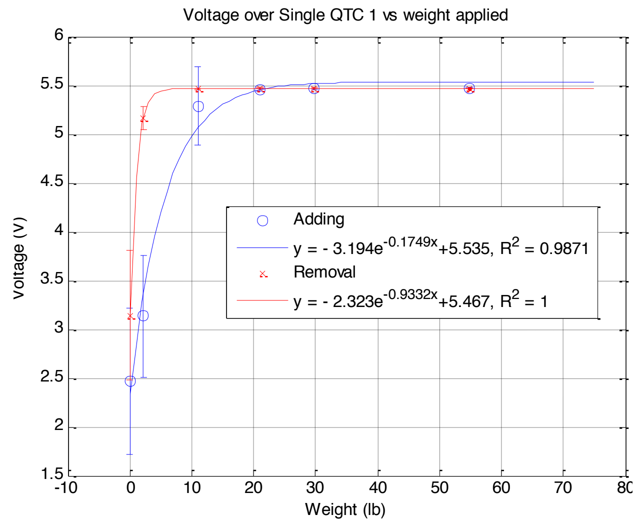

Figure 4. Voltage vs weight of QTC Position 1 (Individual)

Table 1. Hysteresis of QTC (individual or stacked) at each position

QTC Position	Hysteresis	
	Individual	Stacked
1	13.7096	9.8591
2	52.2823	17.9518
3	33.9639	23.1384

DISCUSSION

As seen in Figure 3, the raw data shows the QTCs' response saturating under load, and hence they would be more ideal to be used as switches rather than sensors for pressure mapping. The flattened response after 21 pounds, or after about 90 seconds, is not ideal as wheelchair users exert over 50% of their body weight on the seat pan [8].

The extent of the hysteresis demonstrated may also affect the QTCs' viability for the MW-VSC. Pressure would be continuously exerted in the seat pan, which would continuously compress the QTC pills unless there were additional structural components added such as springs or stands. With the pills in a continuous compressed state, the pressure tracking would be skewed for the next scheduled pressure relief action.

The data could have been affected by a variety of factors. The weight may not have been exactly centered, though this may more accurately reflect reality as everyone sits naturally with their unique pressure distribution. The copper tape used may also have minute deformations in the form of wrinkles that could affect the QTC's voltage at a particular weight, so care is necessary to minimize wrinkles during placement of the strip. Based on the fluctuations, the lighter weights may not also have been steadily placed on the testbed, which detracts from wholly characterizing the QTC. In terms of the MW-VSC however, this is not as big of a problem since half of the average human weight is about 50 to 70 pounds. However, as aforementioned, the QTC response peaks after 21 pounds. Wood is also pliable compared to plexiglass, so using a wooden block as a base may have contributed to additional deformation of the QTC, so both blocks should be plexiglass. An advantage to using plexiglass, other than its stiffness, is that its transparency allowed a bird's-eye view of the placement of the QTC and whether they shifted off the copper strip.

CONCLUSION

Quantum tunneling composites (QTCs) are polymer-metal composites with potential for various applications, particularly as pliable, small, inexpensive switches. While there were numerous limitations, the QTCs behaved as expected, as supported by the multiple curve fits with high correlation. The results support that QTC pills would not be viable as sensors for the MW-VSC. This system may work for children, who weigh less than adults. The resemblance to a switch is not desired, so other sensors should be considered. Other alternative sensors that may be used include: SEN-10-245 load sensors sold by SparkFun or the LPS25HB sold by STMicroelectronics, which can handle 40-50kg and 26-126kPa respectively [9,10].

Further characterization of the QTC pills include: settling time, time to return to uncompressed state, deformation characteristics and relationship between resistance and linear displacement.

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